VTT Technical Research Centre of Finland

Traceable measurement of transmitted overvoltages in instrument transformers

Elg, Alf-Peter; Garnacho, Fernando; Garcia, Tomás; Rovira, Jorge; Hällström, Jari; Nieminen, Tatu

Published in:
CIGRE Science and Engineering

Published: 01/12/2019

Document Version
Publisher's final version

Traceable measurement of transmitted overvoltages in instrument transformers

A. P. ELG[1]*, F. GARNACHO[2], T. GARCÍA[2], J. ROVIRA[2], J. HÄLLSTRÖM[3], T. NIEMINEN[1]
[1]RISE Research Institutes of Sweden
[2]FFII-LCOE, High Voltage Technological Centre, Spain
[3]VTT-MIKES, Technical Research Centre of Finland

Abstract:

Transmitted over-voltages on instrument transformers are becoming a concern for the grid operators due to the risk of damaging the instruments and control systems connected to the low voltage side. Present methods allow for low voltage tests; however, traceability is lacking for these waveshapes and assessments of measurement uncertainties.

The test referred in the clause 7.4.4 of IEC Standard 61869-1 is used to check the overvoltage that appears on the secondary terminals of instruments transformer when a specified overvoltage is applied to the primary terminals.

The general test procedure is indicated in IEC 61869-1, but no specific requirements are given, such as the test voltage level to be applied, or how the peak value should be measured, or which are the requirements to be satisfied by the measuring instruments.

These specific requirements can significantly influence the test result.

The aim of this paper is to present a method for traceable measurement of transmitted over-voltages in voltage instrument transformers. The present IEC 61869-1 standard defines the limits of permissible transmitted over-voltages by using low voltage impulses.

However, the Standard does not state the measurement uncertainties for the measurement.

The testing setup for the determination of transmitted over-voltages consists of a high voltage impulse generator generating a wave shape of 0.5/50 µs up to 250 kV. A reference measuring system simultaneously records the applied wave shape and the transmitted overvoltage. A wideband attenuator is connected on the secondary terminals of the tested transformer.

We present a traceability chain for 0.5/50 µs impulse shape. Measurements results are presented for four different types of instrument transformers commonly found in high voltage grids; a 145 kV inductive voltage transformer, a 400 kV and a 132 kV capacitive inductive voltage transformer (CVT) and a 145 kV capacitive voltage divider.

Measurements show that LV tests may both overestimate and underestimate the transmitted overvoltages in voltage transformers. In one case the difference was as large as a factor of two compared to measurements at full voltage. No requirements on neither the method nor the measurement system for the LV test, e.g. no requirements on the transient recorder, combined with voltage non-linearity of the phenomenon and undefined burden in the voltage transformer lead to unacceptable large errors and measurement uncertainties.

Generation of impulses with 0.5 µs front time is difficult without excessive overshoot.

Conditions in the power grid have long since been standardised to LI withstand tests with a shortest wave front of 0.84/50 µs. Our recommendation is to use a standard LI wave shape of 0.84/50 µs and do full voltage tests with the same well specified requirements.

1. Introduction

In the HV grids lightning strikes and switching transients are present on the HV end of measurement and protection transformers. These transients are transmitted to the secondary side of the transformer and may harm the LV instruments and control systems. Depending

* alf.elg@ri.se

on the design of the transformers, these transmitted over-voltages are to some extent suppressed. Test of transmitted over-voltages in instrument transformers is

routinely performed as a type test, but present methods allow for application of low voltage at the HV terminal. This over-simplified testing is probably owing to that traceability is lacking for HV testing of such waveshapes.

The work here is based on real HV tests, with prescribed 50 W termination only and with a correct burden. These measurements are compared with LV measurements to see if the pass/fail criterion is affected.

2. The present method

The LV test described in clause 7.4.4 of IEC standard 61869-1 [1] describes the method used to record the overvoltage on open secondary terminals of instrument voltage transformers when a 0.5/50 µs impulse is applied to the HV terminal [1]. Neither specific requirements are given e.g. for the test voltage level to be applied, nor how the peak value of the transmitted overvoltage should be measured. The set-up in IEC 61869 also does not reflect the requirements for the measuring instruments when in use, e.g. instead of nominal burden use of 50 W termination is specified.

Assessment of measurement uncertainty for the LV tests is not required by IEC 61869.

3. HV Measurements

Three different types of voltage transformers were tested in this study. A Marx generator is tuned to give wave 0.5/50 µs impulse shapes as prescribed by the standard [1], in 5 voltage steps up to U_p = 1.6×Ö2/Ö3×U_m.

3.1 Measurement set-up

The devices under test for transient over-voltages were connected to an impulse generator from a common point in a Y shape against two reference dividers as prescribed in IEC 60060-1 [2]. One of the inductive voltage transformers, an Arteche UTE-170, is in the foreground in Figure 1. The secondary terminal was connected via a 50 Ω cable of type RG58 to a transient recorder with 50 Ω termination as described in the standard [1].

Figure 1: A HV measurement set-up for a test of an inductive voltage transformer (right) mounted at the common point.
The ASEA reference divider (left).

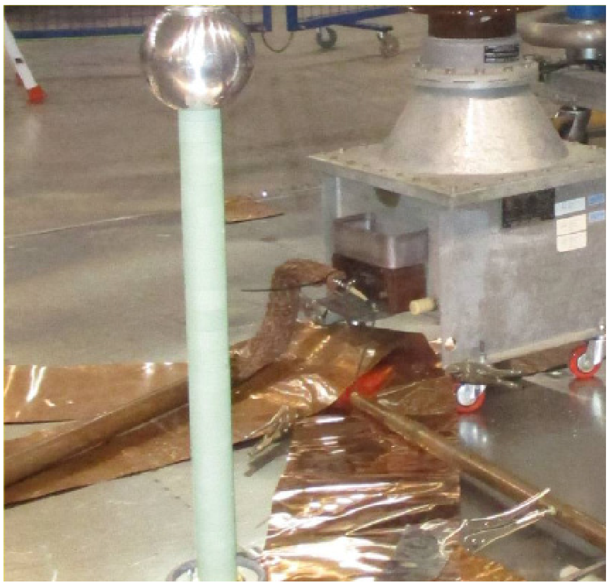

Figure 2: An enlargement of the connection to the secondary of the DUT. Note the copper tubes used for screening. The second reference divider is sitting in the foreground.

Two measurement systems were used in parallel, both sampling the HV but either sampling the very fast transient overvoltage (VFTO) from the secondary of the DUT.

The first consisted of a voltage divider of type ASEA YDSA 600 kV (Fig. 1) was connected to one channel of an oscilloscope of type Yokogawa DL350 with 10 GS/s sampling rate and 1.5 GHz bandwidth, another channel simultaneously sampling the VFTO from the secondary of the DUT.

The second consisted of a voltage divider of type PIKA VFT600 [3] (Fig. 2) was connected to one channel of a transient recorder of type National Instruments PXIe-5164 with 1 GS/s sampling rate and 400 MHz bandwidth, another channel simultaneously sampling the VFTO from the secondary of the DUT. This transient recorder has 14 bits dynamic range with >11-bit effective number of bits (ENOB) and a settling time of 4.5 ns [4].

3.2 Interference test

As seen in Figure 2, copper tubes were used to screen the RG58 cables for common mode suppression. Interference test was performed by shorting and grounding the cable terminals at the DUT end. Recordings of the signal level were made at the highest high voltage level to ensure that the screening was efficient enough. Comparing the peak value of the interference of 5.5 mV, shown in Figure 3, with the VFTO signal of 180 V in figure 5, we have an interference level of 0.3%.

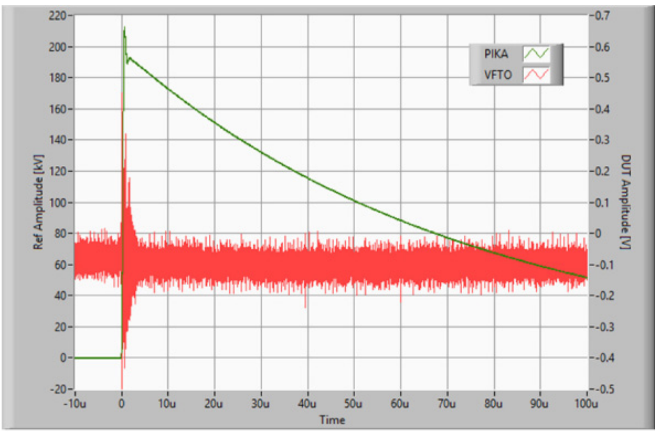

Figure 3: Applied impulse on the HV (green, left) and measured of interference induced in the cable and transient recorder used for VFTO (red, right).

Interference test of the reference measurement systems, described in in IEC 60060-2, shall be performed using with a rod-plane discharge in free air, chopping the full wave after 2-5 µs. The criterion for an approved test is 1% which is fulfilled here.

3.3 Calibration of measurement systems

A step response is applied to the input of the transient recorder with and without the reference divider, after which the settling time is calculated according to IEC 60060-2. The settling time gives an indication of the contribution if errors for time and peak parameters the measurement system in the current set-up. Using the step response and convolving with ideal test curves gives the measurement uncertainty. Extending this calibration for 1 MΩ input, a calculable calibrator [5] for 0.5/50 µs impulse shapes was used. Other uncertainty contributions were established according to IEC 60060-2 [2].

4. Results

Four voltage transformers of different make and type were put to test; one VT, two CVTs and one DOVT (CVD).

4.1 Arteche VT 145 kV

The VT has an Um=145 kV, and it was tested up to 250 kV. The test prescribes a maximum voltage of 189 kV, but it was decided to go further to test effects of saturation. The applied 0.5/50 µs wave shape and the recorded overvoltage for 200 kV impulse is shown In Figure 4. The measured transmitted voltage is in this case 180 V.

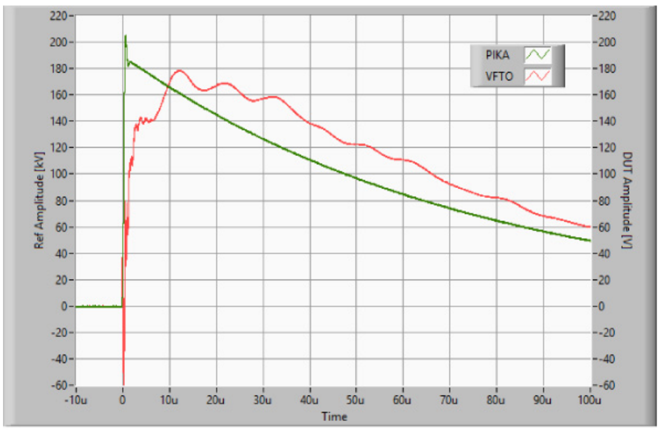

Figure 4: Applied impulse on the HV (green, left) and measured transmitted overvoltage (red, right)

Using the lowest possible voltage from the impulse generator a measurement at 1.6 kV is shown in Figure 5. Evaluating the curve according to [1] gives a value of 1.1 V for the transmitted voltage.

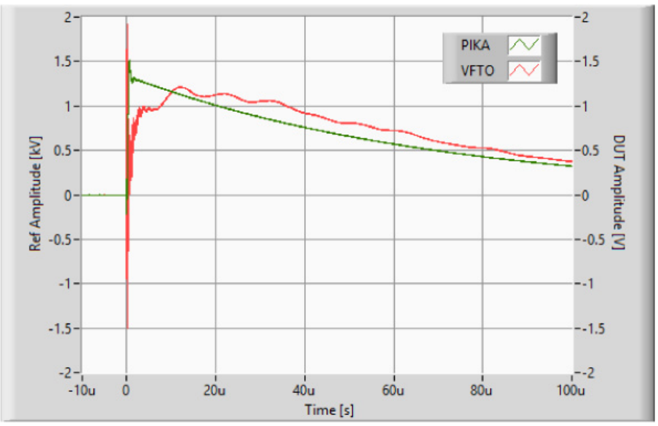

Figure 5: Measurement of VFTO at 1.6 kV.

Now we check the validity of the LV measurement against the HV measurement. The principle described in the standard [2] is based on extrapolation from LV to the limit as given in (1):

$$U_s = U_p \cdot U_2/U_1 \qquad (1)$$

where: U_s = Estimated overvoltage [V]
U_p = Maximum test voltage [V]
U_2 = Measured overvoltage [V]
U_1 = Applied voltage in the test [V]

After doing the evaluation according to equation (1) for all measured values U2/U1 we arrive at the result shown in Figure 6, where it is apparent that the tests of this VT below 1 kV gives an underestimate for full voltage, even though it passes the test, i.e. VFTO <1.6 kV.

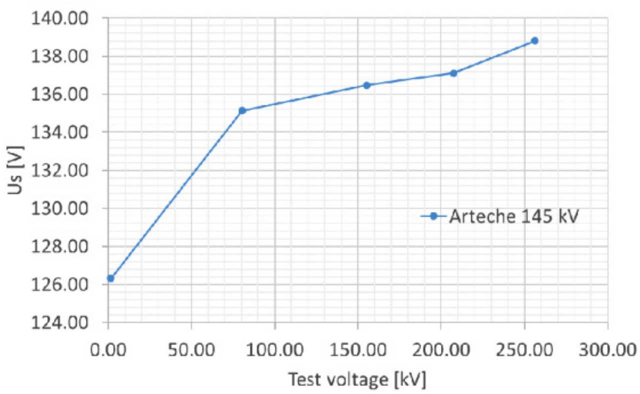

Figure 6: Calculated transmitted overvoltage Us as function of test voltage for VT Arteche 145 kV.

4.2 Haefely CVT 396 kV

The measurement results for this capacitive voltage transformer (CVT) is shown in Figure 7. The nominal phase voltage is 396/Ö3 kV but the test was performed at 45 kV, much lower than the prescribed 517 kV

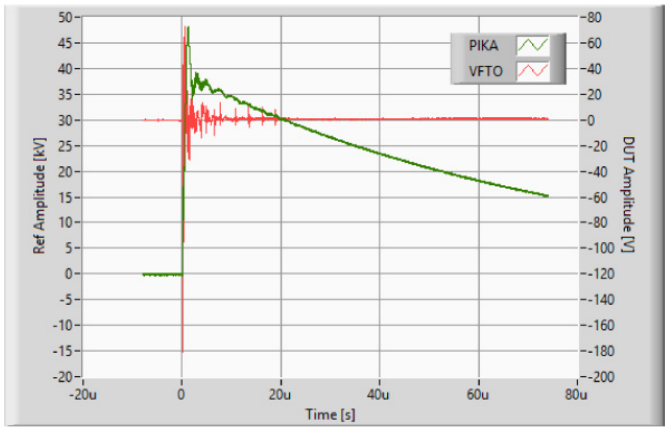

Figure 7: Applied impulse on the HV (green, left) and measured transmitted overvoltage (red, right) for the CVT 396 kV.

Due to the large capacitance of the DUT, i.e. 4.7 nF, the wave front achieved was with a 0.97 µs, much longer than the target 0.5 µs ±10%. When using the correct burden instead of open end, the transmitted voltage on secondary had an amplitude of - 180 V.

The combination of capacitive HV with inductive LV part seems to excite fast transients due to resonance. The observed fast transient at the beginning of the impulse is shown in Figure 8. It is recorded with measurement system described in section 3.1. These fast transients and high amplitudes need some attention since they would harm electronics, and the 100 MHz bandwidth oscilloscope defined in [1] is not enough to capture them.

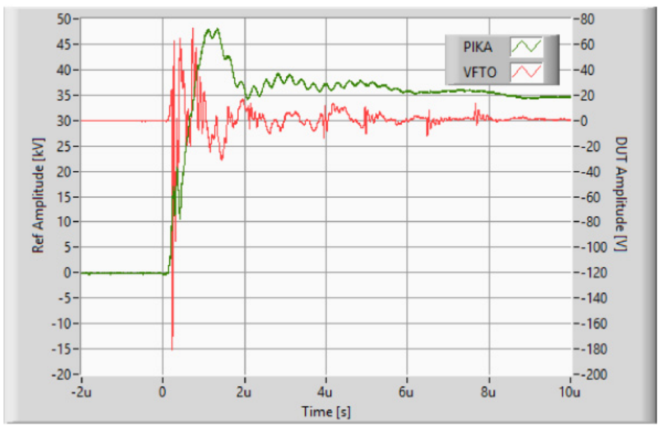

Figure 8: A time zoom of Figure 8 of the transmitted overvoltage (red) for the CVT 396 kV

The VFTO in the CVT is clearly not behaving as for the inductive Arteche VT, where the peak voltage could be evaluated as given in [1]. By scaling the peak of -180 V to full primary voltage of 517 kV, the VFTO reach 2.0 kV, which surpasses the limit of 1.6 kV. Using an open end as described in the standard, the overvoltage for 45 kV excitation became even worse with an amplitude of 320 V.

This transformer is equipped with an overvoltage protection of varistors, probably installed to clamp impulses to acceptable levels.

4.3 Asea CVT 132 kV

A CVT with nominal phase voltage 132/Ö3 kV was tested up to 170 kV. The CVT has a rather high capacitance of 16 nF, which makes the generation of short wavefronts of 0.5 µs hard to achieve.

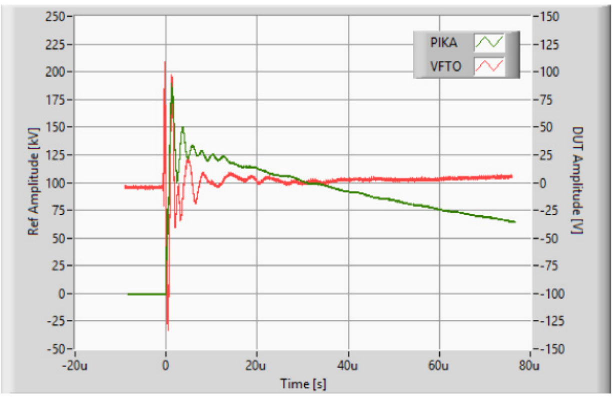

Figure 9: Applied impulse on the HV (green, left) and measured transmitted overvoltage (red,right) for the ASEA CVT 132 kV.

The transformer has a large negative VFTO undershoot, like the Haefely CVT 396 kV shown in Figure 8. This seems to be typical for these transformers. Using (1) for all measured values U2/U1 we arrive at the result showed in Figure 10.

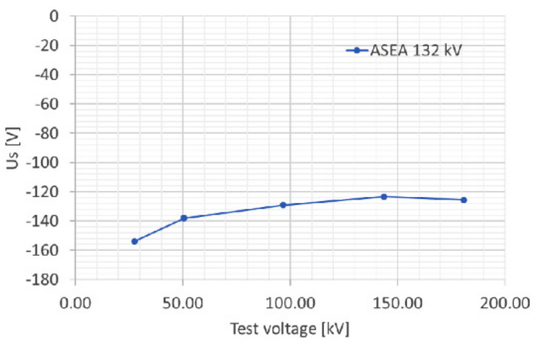

Figure 10: Calculated transmitted over voltage Us as function of test voltage for CVT ASEA 132 kV

In this case (1) gives an overestimate of VFTO measured at low voltage (155 V) compared to full voltage (125 V).

4.4 Capacitive voltage divider (DOVT 145 kV)

A digital optical capacitive voltage divider, normally designated CVD, but marked as type DOVT 145 was built by ABB in 1999. The transformer has a nominal phase voltage 145/Ö3 kV, and it was tested up to 190 kV. The HV capacitance is 12 nF, which limited the wave front to 0.81 µs. We see in Figure 11 that also this transformer has front oscillations which are higher than the transmitted VFTO, even though this capacitive divider as the purely inductive LV part to suppress the transients.

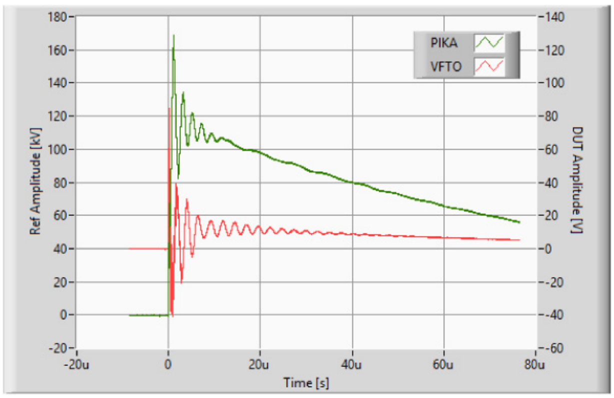

Figure 11: Applied impulse on the HV (green, left) and measured t ransmitted overvoltage (red, right) for the ABB DOVT 145 kV.

After evaluation of the extreme voltage of the VFTO, we get the result in Figure 12. As is seen in this figure even though the VFTO are far below the limit of 1.6 kV at full voltage, it is apparent that (1) is overestimating the maximum value by a factor of 2.3 measuring at 25 kV, i.e. 115 V compared to 50 V at full voltage.

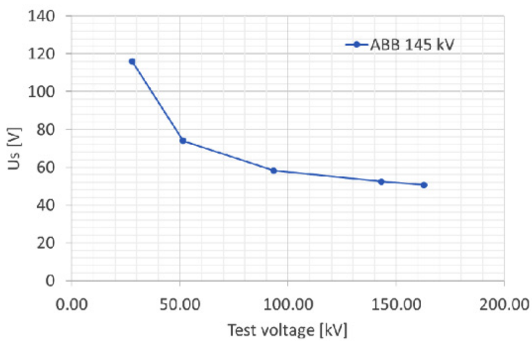

Figure 12: Calculated transmitted over voltage Us as function of test voltage for DOVT 145 kV.

5. Discussion

After getting results applying full voltages to the primary instead of the 1 kV defined in IEC 61869-1, the results are hinting that the standard procedure overestimated the transient by a factor of two or more. Also, the standard test in many cases leads to secondary voltage below 1 mV. Typical 8-bit instruments have a minimum setting of 2 mV per division, together with 100 MHz bandwidth requirement [2], the ENOB typically goes down to 5-6 bits. Without defining the dynamics, noise level of the transient recorder oscilloscope, the measurement uncertainty at these levels could easily be ±30 %.

6. Recommendations

Instead of requiring 0.5 µs front time, the short front of LI, i.e. 0.84/50 µs, might be used instead. Traceability exists for this standardized waveshapes, and many established installations are available. Performing the measurement at full voltage leads to much lower uncertainty for the transmitted overvoltage measurement. In defining the transmitted overvoltage test, more guidance could be followed, and references might be made to the existing for HV measurement [1] and transient recorder [6] standards for qualification and uncertainty estimates.

7. Conclusions

The findings are that the present standard [1] allowing for LV tests of VFTO in instrument voltage transformers have in one case showed overestimate of a factor of 2.3 at 25 kV compared to full voltage at 189 kV. Performing the LV test, which has no requirements neither for the method nor for the measurement system, leads to larger errors and measurement uncertainties than expected.

In the standardized test the correct burden is not used, which seems to lead to overestimation of the transmitted voltage. Generation of wavefronts of 0.5 µs are difficult to achieve without excessive overshoot and conditions in the power grid have long since been standardised to LI withstand tests with a shortest wave front of 0.84/50 µs. Our recommendation is to use a standard LI wave shape of 0.84/50 µs and do full voltage tests with the well specified requirements for instrumentation in IEC 60060 and IEC 61083.

8. Acknowledgments

The work reported here has received support from the EMPIR programme co-financed by the Participating States and from the European Union's Horizon 2020 research and innovation programme.

Identification of certain equipment does not imply recommendation by the authors, nor does it imply that the equipment is necessarily the best available for the purpose.

9. References

[1] *IEC 61869-1 "Instrument transformers - Part 1: General requirements"*

[2] *IEC 60060-2. Ed.3.0 (2010), "High-voltage test techniques - Part 2: Measuring systems"*

[3] *J. Hällström, S. Kazmi, J. Havunen, M.-L. Pykälä, "Design and performance of a fast divider for puncture testing", 20th ISH, Buenos Aires, Argentina, 2017, Paper 470A.*

[4] *A-P. Elg, "Qualifying a transient recorder for traceable measurements of very fast transients", Conference on Precision Electromagnetic Measurements CPEM, Paris, France, July 2018.*

[5] *J. Hällström, "A calculable impulse voltage calibrator," Ph.D, Electrical and communications engineering, Helsinki University of Technology, Espoo, Finland, 2002.*

[6] *IEC 61083-1 "Instruments and software used for measurement in high-voltage impulse tests - Part 1: Requirements for instruments"*